Analysis of the BTeV Vertex Detector Vacuum System

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Introduction

The BTeV experiment contains its pixel detector inside a vacuum vessel. The specified vacuum pressure for the region where the beam is located is less than $1\text{x}10^{-7}$ torr. The current design of the pixel detector splits the vacuum vessel into two regions. A thin membrane, which is also used as the RF shield, separates the pixel assembly from the beam. The hypothesis is that the beam region would be cleaner than the pixel region, which contains a large gas load due to outgassing of material in the detector. However, the RF shield does not completely isolate the pressure of one region from the other. There is a gap between the RF shield and its support to the vacuum vessel to allow movement of the shield. The gap acts as a place for restrictive flow between the two regions. Figure 1 is an illustration of the vacuum vessel split into two regions by the RF shield.

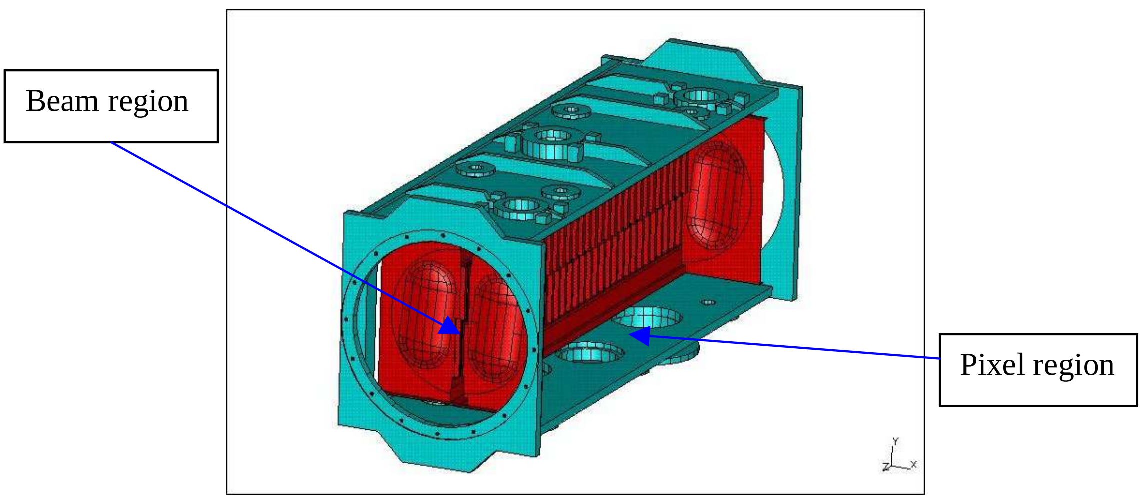

Figure 1 – Illustration of RF Shields That Divide the Vacuum Vessel

The purpose of this report is to show the analysis of the conductance between the beam ("clean") region and the pixel ("dirty") region. Given the geometry of the components in the vacuum vessel, the restrictive gap between the regions, and the total gas load of the pixel, a model is created to show pressure of the region where the beam travels.

Gas load due to outgassing of the material in the pixel detector

The total gas load due to outgassing inside the vertex detector is estimated at about $1\text{x}10^{-1}$ torr-L/sec. The total surface area of the exposed material in the vertex detector is approximately 30 m^2 and assuming an outgassing rate of $3\text{x}10^{-7}$ torr-L/cm^2-sec. The assumption is that the surfaces are at room temperature. The specific outgassing rate used is based on the lower range for common non-metallic materials[2]. For comparison this outgassing rate is only a factor of 3 higher than the measured value for kapton[3]. Many of the materials should be expected to have outgassing rates that are significantly higher than kapton. With the conversion of 1 torr-L equaling $3.5x10^{19}$ molecules at 273K, the gas load in terms of molecules is about $4x10^{18}$ molecules/sec.

Evaluation of the conductance between pixel and beam regions

Figure 2 is a schematic of the RF shield. The locations whose pressure is of interest in the vacuum vessel are the collision point and the entrance to the beam pipe. There are two ways that the gas from the dirty region can pass into the clean region, labeled JA and JB in Figure 2. The gas then travels through the gap between the RF shields. This is labeled GAP in Figure 2. Also, the gas travels through the square cross sectional region, labeled BA, where the beam travels between the RF shields. The gas can also travel into the beam pipe BP. Lastly, the gas can travel from the dirty region into the cryopump CR.

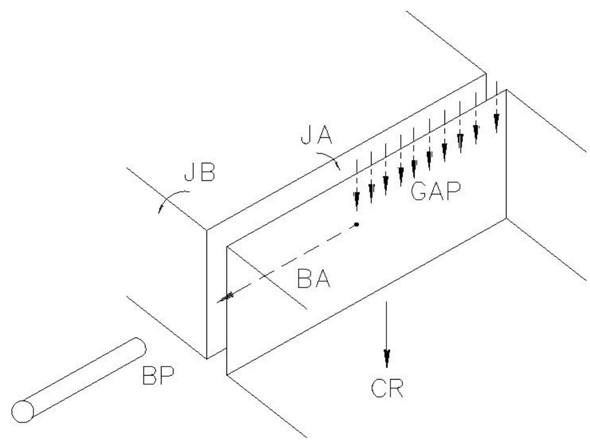

Figure 2 – Schematic of the RF Shield

The conductance path is analogous to an electrical circuit, as shown in Figure 3. The circuit also takes into account the pumping speed in the pixel region, the conductance of the beam pipe, and the non-evaporable getters located in the regions between the side of the RF shield and the vessel's end window. NEG represents the total pumping speeds of the non-evaporable getters. CR is the total pumping speed of the cryogenic pump for the pixel region. Q represents the total gas load coming from the dirty region. The ground symbol represents the region outside of the vacuum vessel.

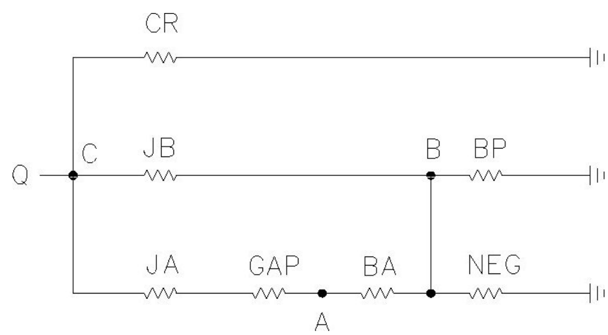

Figure 3 – Model for Vacuum Vessel

The conductance of each region is calculated by assuming each region is a tube of either a round or rectangular cross section. The general equation for the conductance of air [1] by molecular flow at 22°C is

$$C = 11.6*a*A$$

where C = conductance (L/sec)
a = transmission probability that a molecule entering the tube will leave the tube at the other end
A = tube cross sectional area (cm^2)

To begin, the conductance of the beam pipe is calculated. The dimensions of the flow region are 2.5 cm in diameter and length 3 m. The ratio of length/diameter is 120. The transmission probability for a round tube with l/d = 120 is about 10^{-2}. The cross sectional area is about 5 cm^2. Equation 1 is then used:

$$C = 12 * 10^{-2} * 5$$

$$C = 0.6 \ \ L/sec$$

The conductances of all paths are calculated in a similar manner. Table 1 lists the path dimensions and conductance. The pumping speed of the cryo pump is included.

Table 1 – Conductances in the Vacuum Vessel

Path	Symbol	Length l (cm)	Width (cm)	Thickness (cm)	Diameter d (cm)	l/d or l/b	a	A (cm2)	C (L/sec)
Beam pipe	BP	300			2.5	120	10^{-2}	5	0.6
Beam area	BA	70	1	1		70	10^{-2}	1	0.1
Gap	GAP	25	150	1		25	10^{-1}	150	400
RF shield Long edge	JA	6	600	0.3		20	0.15	180	300
RF shield Short edge	JB	6	240	0.3		20	0.15	72	130
Cryo pump	CR								800

Regarding the gap between the RF shields, the width includes the top and bottom regions between the shields. Regarding the long edges of the RF shield, the width takes into account length of the top and bottom edges of both shields. As for the short edges of the RF shield, the width includes four edges on the sides of the shields.

Evaluation of the pressure in the beam region and at the entrance of the beam pipe

Figure 4 shows the values of the conductances in the system. Point A represents the pressure inside the beam area between the RF shields. Point B is the pressure at the entrance of the beam pipe. Point C represents the pressure in the dirty vacuum region. The total pumping speed of the non-evaporable getters (NEG) is not specified. However, its presence is shown to illustrate its effect on the pressures that are of interest.

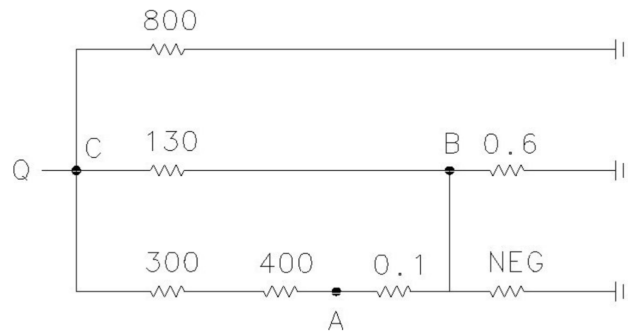

Figure 4 – Model of Vacuum Vessel

From the model, it is shown that the combined conductances of the long edges of the RF shields and the gap in between RF shields result in the pressure at the collision point (point A) equaling the pressure inside the pixel region (point C). The smallest pressure at the entrance of the beam pipe (point B) can be half of the pressure in the pixel region if the total pumping speed of the non-evaporable getters is 200 L/sec. In other words, the RF shield in its current design does not divide the vacuum vessel into two distinct regions in terms of vacuum pressure. The pressure in the beam region is essentially equal to the pressure in the pixel region. The cryo pumps, with a total pumping speed of 800 L/sec, are the only effective tools to control the vacuum pressure. Knowing that the gas load in the pixel region is 10^{-1} torr-L/sec, the pressure in the vacuum vessel, both in the pixel region and in the beam region, is calculated as

$$P = \frac{10^{-1}\text{torr} - \text{L/sec}}{800\ \text{L/sec}} \cong 10^{-4}\text{torr}$$

Thus, the expected pressure in the pixel region and at the collision point inside the beam region is a few 10^{-4} torr. The pressure at the entrance of the beam pipe could only be a factor of two lower than 10^{-4} torr having two non-evaporable getters of 100 L/sec each.

Design modifications

The expected pressure in the beam region for the current design is higher than the required pressure by at least three orders of magnitude. To decrease the pressure in the area where the beam is located, it is necessary to modify the design of the vacuum system. In order to reduce the pressure the pumping speed should be increased and the outgassing rate in the pixel region be decreased. Since there is no room to increase the pumping speed by a few orders of magnitude, the only alternative is to add a cryopump inside the pixel detector itself. The cryopump will increase the pumping speed in the region. In addition, having the cryopump inside the pixel region results in decreasing the overall temperature in the vaccum and thus reducing the outgassing rate.

As an academic exercise, let us evaluate the scenario of completely sealing the gap between the RF shields along the top and bottom edges. Can the vacuum vessel stay at room temperature and keep the pressure less than $1x10^{-7}$ torr? Let the volume in the gap contain non-evaporable getters that contribute a total pumping speed of 400 L/sec. With the geometry of the square cross-sectional beam region, the conductance through beam area is 400 L/sec. The total conductance of the region becomes 200 L/sec. To have a pressure of $1x10^{-7}$ torr in the region, the gas load should be

$$Q' = 10^{-7} \text{torr} * 200 \ \frac{\text{L}}{\text{sec}} = 2\text{x}10^{-5} \frac{\text{torr} - \text{L}}{\text{sec}}$$

The surface area of the beam region is roughly 2 m^2. In order to obtain the desired pressure of 10^{-7} torr inside the beam region, the ougtassing rate must be $1x10^{-9}$ torr-L/cm^2-sec. It is unlikely that the RF shield can be treated to achieve this outgassing rate at room temperature. In other words, running the pixel vacuum system at room temperature, even with the sealed RF shield design, may still not result in the desired pressure in the beam region.

Let us evaluate the pressure of vessel if it is to have a total of four cryopumps working in the silicon region. The temperature of the majority of the pixel detector will be lowered to cryogenic temperatures. However, the total outgassing will be between one and two orders of magnitude lower because the same fraction of the outgassing surface will not be cold. The water vapor pumping speed is proportional to the surface area of the cryopanel front surface at a rate of 15 L/sec-cm^2. The total surface of the four panels installed inside the silicon region is greater than 1m^2. For an unobstructed panel the water vapor pumping speed could be greater than 10^5 L/sec. However, the actual geometry can limit the real pumping speed to 10^4-10^5 L/sec. The water partial pressure in the pixel region should range between 10^{-6} to 10^{-8} torr. It should be noted that at 100K the density is the same as the density at room temperature when the pressure is a factor of three lower.

The pressure inside the beam (clean) region could be lowered further by cooling down the RF shield to make it work as a cryopump. Also, the long edge of the RF shields can be modified by adding an elastic seal or bridge to the two sides of the RF shield. If the open joint along the side of the RF shield can be designed with a conductance one-tenth of the expected pumping speed for water of the cold RF shield, the pressure inside the beam region between the RF shields should be another fact of ten lower. At present it not clear how to make a thermal connection to lower the RF shield to liquid nitrogen temperature.

Before the final decision is made to cool the vertex detector, it is necessary to make the following tests:

1. Analyze the gas released from a representative sample of the pixel detector components. Note that the previous analysis assumes that the majority of the outgassing is due to water vapor and other gases with low vapor pressure.
2. Verify that it is safe to thermally cycle the silicon detector to liquid nitrogen temperatures.
3. Design the sides of the RF shield in order to lower the conductance less than 100 L/sec and design a thermal connection to lower the RF shield to liquid nitrogen temperature.

References

1. O'Hanlon, J.F. A User's Guide to Vacuum Technology. Second Edition, John Wiley and Sons, New York, 1989.
2. Figure 4.30 Outgassing rates of various untreated materials at room temperature, Roth, A. Vacuum Technology. Second Edition, North Holland, 1989
3. private communication Ferro-Luzi, M, May, 2000